Coastal Hazard Assessment Along the Blue Beach Fossil Cliffs, Kings County

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Background and Scope of Report

During the spring and summer of 2010, Department of Natural Resources (DNR) staff undertook a detailed assessment of geohazards along a section of coastline in the area of the Blue Beach fossil cliffs (Fig. 1). This assessment was undertaken in response to a request from the Municipality of the County of Kings planning department.

The Blue Beach fossil cliffs constitute one of the most important sites worldwide in recording the adaptation of vertebrates to life on land some 350 million years ago. The significance of the site warrants an attempt to have it recognized as a UNESCO Geo-Park. This is a designation that serves to advertise and enhance the recognition of a site's importance, and can positively impact economic development in the area.

The purpose of this report is to provide an evaluation of the rate and style(s) of coastal erosion along the Blue Beach fossil cliffs. This is a geological hazard assessment and should not be confused with a slope stability assessment. A geological hazard assessment includes much of the information that would be found in a slope stability assessment. However, a slope stability assessment also includes things such as measurements of soil cohesion, friction angle, soil density and calculation of Erosion Hazard Limits. Slope stability assessments must be carried out under the supervision of a geotechnical engineer. The document *Slope Stability Guidelines for Development Applications*, produced by the City of Ottawa (2010), is an excellent guide in determining minimum requirements for slope stability assessment reports and is adopted here. For the purpose of this study the authors examined approximately 600 m of shoreface.

Setting and Previous Work

The study area lies in the upper Bay of Fundy along the Avon River (Fig. 1), which is a macro-tidal environment with a maximum tidal range of 16 m (van Proosdij and Baker, 2007). The study location is approximately 16 km downstream from the causeway at Windsor. An analysis of the effects of the Windsor causeway by van Proosdij and Baker (2007) provides valuable background information on the rates of change of the width of the Avon River. This analysis was done using orthorectified aerial photographs (1969, 1976 and 2005) as well as a survey chart from 1858. VanProosdij and Baker (2007) estimated approximately 100 m of cliff erosion since 1858 on the western shore, Line 19, near the Blue Beach area, and an increase in the intertidal cross sectional area of between 2% and 3.5%. Mossman,

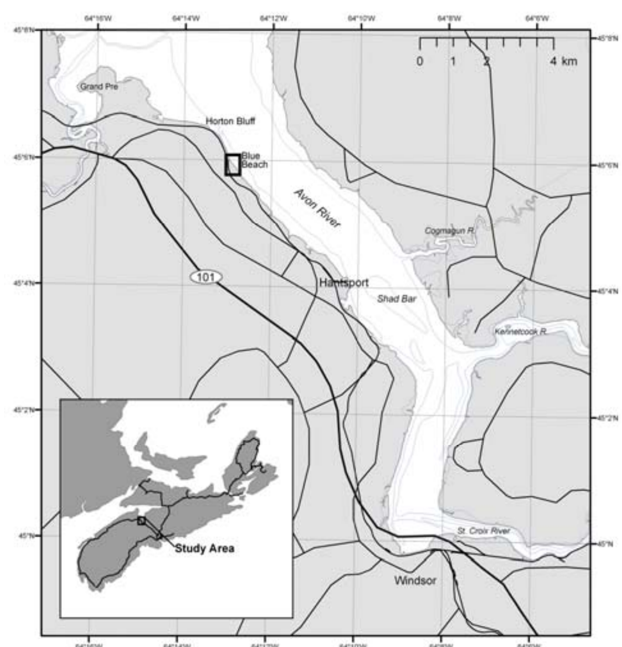

Figure 1. Location map of the study area at Blue Beach, Kings County.

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(personal communication, 2010) suggested that such an increase in width would lower wave energy impacting the shoreface.

Amos and Lang (1980) assessed the sedimentary character of the Minas Basin, including the mouth of the Avon River. They calculated a mean cliff recession rate of 0.55 m/yr with two standard deviations of ±0.54. Thus, recession rates varied from near zero to over 1 m/yr. Desplanque and Mossman (2004, p. 85), referring to the Bay of Fundy, state “that the shoreline will have a tendency to retreat at a rate of 0.06 m to 0.8 m/yr depending on the slope of the foreshore and the resistance to erosion of shoreline materials.” The low rates refer to basalt and other crystalline rocks, whereas the high rate refers to “erosion-prone sandstones and conglomerates.” Desplanque and Mossman (2004) do not present data or refer to other publications for these rates, but they are consistent with those calculated by Amos and Lang (1980) and vanProosdij and Baker (2007).

The rates discussed above reflect long-term average erosion rates across large geographic areas. These erosion rates are not necessarily applicable to a site-specific assessment such as the present study at Blue Beach, but provide a framework to compare to the author’s results.

Change Analysis

Archival aerial photographs are a valuable tool for assessing coastal erosion (e.g. van Proosdij and Baker, 2007) and are used universally in long-term change analysis. Along shorelines, they work best where there are rectification points close to the shoreline. The use of long-term imagery series smoothes the erosion rates between air photographs of varying age and allows calculation of average rates of cliff retreat over extended periods of time.

At the Blue Beach study site, the presence of thick vegetation makes it difficult to distinguish slumping along the upper cliff. Defining the position of the upper scarp, between different years, is particularly problematic. In an attempt to address this issue rectified images were used to examine the position of the intersection between the beach and the base of the cliff, as this feature is not obscured by vegetation. This method was ultimately discarded, however, as the control points were only inland and on top of the cliff. There were no control points for rectification on the beach or foreshore. As a result the position of the beach-cliff intersection could be significantly distorted and yield incorrect estimates of long-term cliff base erosion.

It needs to be stressed that the average rate of erosion of a cliff face is only one of many factors that may be considered when undertaking a hazard assessment of a particular site along the shore. As an example, where planning and permitting activities are undertaken, average rates of cliff retreat are important, but recognizing the possibility of both large- and small-scale, short-term cliff edge collapse is equally, or of greater importance. Gradual, long-term erosion is easier to plan for than shorter term, mass wasting events that may occur with little notice. The various factors that need to be considered in a detailed hazard assessment are discussed later in this report.

Local Shoreline

The authors define ‘local shoreline erosion’ as erosion and associated processes occurring and observed on a scale of hundreds of metres both up- and down-shore of a specific site. At the Blue Beach location (Fig. 2) it is necessary to assess the style(s) of erosion (e.g. large-scale periodic mass wasting, slow long-term cliff erosion, etc). There are three main forms of mass wasting along the shore: (1) rock falls, (2) slumps and (3) rock slides and earth flows of overlying till (Bloom, 1978). Slumps and rock slides - earth flows, though separated above as distinct forms of mass wasting, are often gradational into each other, as is the case in the present study area.

Rock Falls

Rock falls occur where a mass of rock breaks off and free falls to the beach, often initiated by processes such as water runoff, undercutting at the base of the cliff, and freeze - thaw cycles. At Blue Beach, undercutting by wave erosion at the beach-cliff interface is present, but erosion of debris that collects at the base of the rock cliff is equally

Figure 2. Air photo showing locations of the photographs referred to in this report. The square outline shows the location of a close-up view of the shoreline where there is a large rotational slump (Fig. 3).

important. Rock debris that free falls from the cliff face is quickly removed, allowing cliff undercutting to proceed. Siltstone and mudstone weather easily and fall to the beach. This undercuts the laterally extensive, but heavily jointed sandstone beds.

Sandstone beds in the cliff face, immediately seaward of the proposed development site, strike 80^0 – 260^0 and dip 22^0 toward the north, sub-parallel to the cliff face but toward the water. The sandstone beds are relatively thin and few in number. In this area interbedded siltstone (siltstone is the predominant rock type) and mudstone exposed in the vertical cliffs are incompetent and subject to erosion, making the cliff subject to undercutting. However, this undercutting is limited by the lack of wave action on the cliff base during normal tides along much of the cliff face in the area of the proposed development.

Slumps and Rock Slides

Slumps at Blue Beach occur in response to several factors; these factors act as both initial triggers for slumping, and to maintain and enhance the slumping process.

Many of these factors, along with local slumps, are visible along the beach and upper edge of the cliff face. Figure 2 shows the locations of a series of photographs (Sites 1 - 6) taken along the shore face during this study. The photographs illustrate features that are typical of unstable coastal cliffs. It is generally accepted that slumps occur when slopes composed of rock, soil or other unconsolidated materials become over-steepened by erosion at the base, with failure along internal plains of weakness, or as a result of many other triggers that reduce the stability of the slope, such as extensive rainfall.

At Blue Beach the interface between the slump and non-slumped material is visible approximately 75 m north of Site 3 (Fig. 2). The slumping involved not just the stony till, but also the underlying bedrock (Fig. 3, top). At the base of the slump, siltstone bedrock is highly deformed, with the appearance of a silt-clay mass where internal structure is almost completely destroyed. It is likely that the triggering mechanism for this slump was failure of the incompetent siltstone between the more competent sandstone beds.

Many other potential triggering mechanisms could be observed. For example, water seeps with associated water seepage pressure within the incompetent siltstone and mudstone, and along sandstone beds; over-steepening of the shore face; loading from overlying rock and glacial sediments; and the presence of faults, joints and fractures. In addition, slip and dilation of bedrock appears to occur along sandstone beds that are moderately dipping to the north toward the shoreface.

Rotational slumps along the shoreface likely fail along main internal plains of weakness in the bedrock, or at the overburden - weakened rock interface, producing a main scarp (Fig. 4), and in some areas multiple secondary slumps internal to the main rotational slump. The result is a series of systematic ridges, tilted landward and decreasing in elevation toward the shoreface. At Blue Beach observed slumps are in excess of 10 m in width, though significant amounts of material were previously eroded and washed away. Thus 10 m is

Figure 3. Rotational slump involving till and bedrock located 75 m north of Site 3, Figure 2.

a minimum width for potential slumps. The total width, which may consist of several internal slumps of varying width, is greater than 10 m. Based on this study the use of 15 m as a ‘working width’ would be reasonable.

The size of rotational slumps may be limited by steeply dipping bedding sub-parallel to the cliff face at this site. The cliff face may be supporting itself along its width, with the gradual flattening of the dip toward the rail slide aiding in this process. An area of particular interest is at Site 2 (Figs. 2 and 5) where evidence for active slumping and erosion can be seen. At this site examination of the cliff - beach intersection (Fig. 5) shows that this line actually prograded (moved seaward) during the 1992 - 2002 time interval. This area of apparent progradation is debris from an earth-flow of till and rock. The apparent (not real) seaward movement of the shoreline is caused by slumps of material falling and sliding down and out over the beach, giving the appearance of seaward movement of the shoreline. The debris was subsequently eroded. The debris comes from the outer edge of a large slump block at the top of the cliff near site 2 (Fig. 2). These slumps are classic examples of rotational slumps (Fig. 4).

In traverses along the upper cliff edge and along the beach at Blue Beach, it was recognized that many features indicate the presence of unstable cliff faces. These features and processes are listed below, and are illustrated in Figures 3-13:

- incompetent, highly fractured, fissile, and easily weathered siltstone and mudstone (Fig. 9);
- sandstone beds that are highly jointed (Fig. 9);
- siltstone/mudstone units overlying and underlying sandstone beds (Figs. 10 and 13);

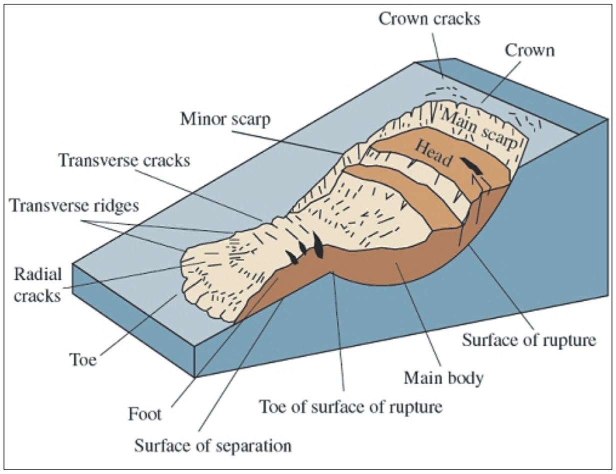

Figure 4. Diagram showing typical rotational slump and its various components (Geological Survey of Canada web site).

- bedded rock layers that strike at a high angle to the shoreface and dip at an oblique angle toward the shoreface (Figs. 3, 10 and 11);
- jointing oriented sub-perpendicular to the rock face;
- sandstone beds that act as slide surfaces for overlying rock (Figs. 3 and 10);
- water seeps along joint surfaces;
- frequent inundation of the cliff base by monthly high-high water events (approximately 20 times a year according to Chris Mansky with the Blue Beach Fossil Museum and Research Center (personal communication, 2010);
- rotational slumps penetrating bedrock and dipping back toward the cliff face (Figs. 3 and 12);
- active slump blocks that take about 10 years to travel from the top to the base of the slope once active movement occurs (Mansky, personal communication, 2010, Fig. 3);
- slump blocks in the initial but progressive stages of detachment from the upper cliff face;
- examples where slumping postdates built infrastructure (e.g. a collapsing stone walled well, illustrating the instability of the upper cliff edge);
- water ponding on the concave upper surface of the slump block at the location of the collapsing well;
- vertical walls of unconsolidated material above active slump blocks (Fig. 3);
- trees tipped outward over the upper cliff edges and slump blocks of rock and soil debris actively moving down slope (Figs. 6, 7, 10 and 11);
- living trees with leaves in blocks of debris lying at the base of the slope (Figs. 6, 7, 10 and 11);

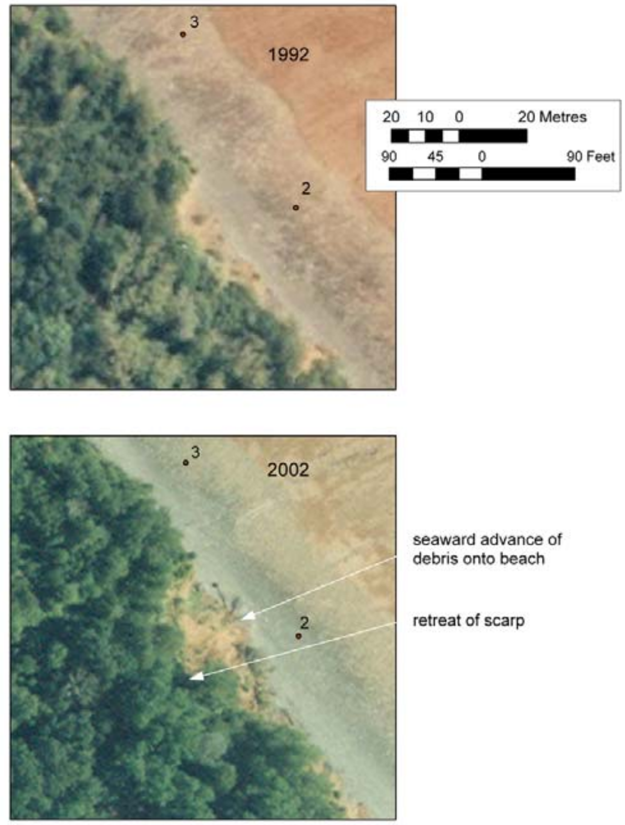

Figure 5 (above). Location is at Site 2 on Figure 2. A comparison of aerial photographs from 1992 and 2002 at a scale of 1: 1000 shows evidence of recent earth flows and slumps.

- piles of rock and debris fans collapsed onto the upper beach edge along the base of the cliff (Figs. 6, 7, 10 and 11).

Regional Shoreline Analysis

In undertaking a geological hazard assessment it is necessary to examine and consider hazards that are identified both locally (e.g. 100 m) and also on a more regional basis. In this instance, regional means within several hundred metres. In examining air photographs, the authors noted two areas of apparent sliding and slumping. The Rail Line Slide near the north end of the study area was examined in detail, in so much as the actual slide area is reforested and/or covered by armour stone. The area to the south is not discussed as it encompasses areas of thick till and is markedly different than the main study area, which is fronted by a steep bedrock cliff.

Figure 6. Example of a recent earth flow of till and rock fall (foreground) at Site 1, Figure 2.

Figure 7. Another view of a recent earth flow of till and rock fall (foreground) at Site 1, Figure 2.

The Rail Line Slide

The Rail Line Slide is a large-scale debris slide that impacted the former rail line. It is approximately 200 m long (measured parallel to the shoreline) and approximately 43 m wide, measured perpendicular to the shoreline (Fig. 12).

This slide (slump) indicates that slides of this magnitude are known to occur in the vicinity of the fossil cliffs. Mossman, (personal communication, 2010) indicated that the bedrock geology at the location of the Rail Line Slide is different than at the Blue Beach site proper, that the bedding is more upright, and that the area was more subject to failure. Outcrop at the area is covered with debris, so the authors were unable to view the bedrock. Outcrop immediately south of the slide (Fig. 13), however, shows bedding that is almost horizontal. Sandstone beds exposed on the beach also lie almost flat.

Figure 8. Fracturing and faulting in the cliff face contribute to slope instability. Arrows indicate the fault line. Location is at Site 3, Figure 5.

Figure 9. Close-up view of the fault in the cliff face shown in Figure 8.

A strength analysis of bedrock at this location would be required to determine the bedrock's susceptibility to failure. Similarly, a strength analysis of bedrock along the rest of the fossil cliff would allow comparison of the corresponding results and enable a researcher to draw conclusions with respect to the potential for failure. In doing so, the exact composition of the slumped material at the Rail Line Slide would need to be determined. For example, is the slide composed of overburden, the upper weathered bedrock, slippage internal to the bedrock, or a combination. Useful information might be obtained by excavating several holes to the bedrock near the top of the beach below the slide area.

The slide area may represent a fault zone where bedrock structure has been disrupted, making it

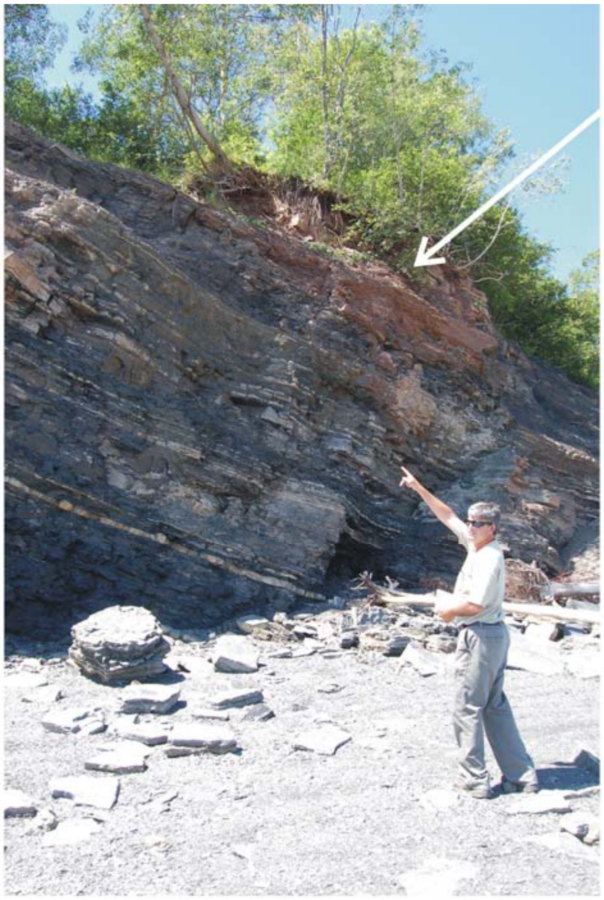

Figure 10. A rock block fall and earth flow in the top right of the photograph. Note the trees still standing in the debris sliding over the underlying sandstone bed.

Figure 11. Camera panned to the right of Figure 10.. Photograph shows a typical rock fall near the proposed development site.

more susceptible to failure. Mansky (personal communication, 2010) suggested that the area represented a natural till-filled depression. Sandstone beds do not outcrop below the slide on the lower shoreface. However, digging revealed blue-grey clay that Mansky suggested was till. Till in the area is a silty-sand with abundant clasts. The material is not till, nor is it a clay till as it still lacks clasts. It is more likely to be weathered siltstone or a siltstone fault gouge. Beach excavation would help to determine the provenance of this material.

It is important to consider the time frame within which the Rail Line Slide occurred or was re-initiated. This cannot be directly determined, as air photographs are not available that are older than 1945. Earlier information relating to this slide might be available in old rail line records, if they still exist. Comparing 1945 imagery with 1955 imagery, it was noted that in the 1955 air photograph the pre-1945 slide was completely re-vegetated over a 10 year period, except for small areas of post-1945 sliding. Similar small-scale slides are visible across successive years of photographs, this being confirmed by Mansky (2010, personal comunication) when he indicated that periodic maintenance was required along the section of rail at the top of the Rail Line Slide.

The Rail Line Slide is clearly visible on 1945 air photographs (Fig. 12), where damage to the rail line can be observed. In addition, it is apparent that both the main part of the slide and its upper edge show little vegetation. This lack of vegetation indicates that the slide occurred, or that major sliding was re-initiated, within the previous 5 to 10 years (1935 – 1940) or less. The slide was stabilized by placement of creosote crib work filled with armour stone at the base of the slide (Figs. 14 and 15), clearly visible on the 1955 image. The age of the Rail Line Slide places it within time frames that must be addressed in hazard or slope stability assessments.

It should be noted that trains no longer use the rail line. Mansky (personal communication, 2010) suggested that shaking and loading from the weight of passing trains may have been triggering mechanisms for the Rail line Slide. This point is certainly worth investigating.

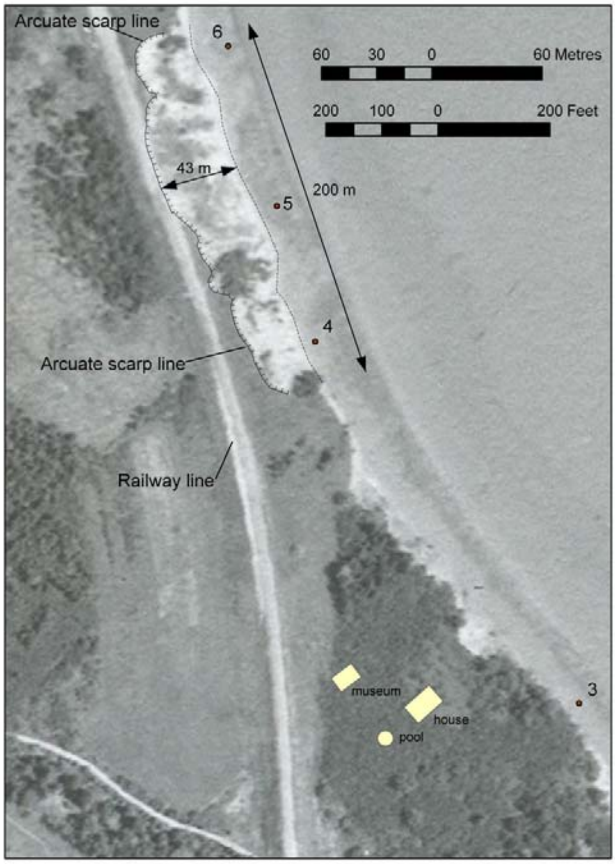

Figure 12. Air photograph of the Rail Line Slide. Numbers with dots are site locations with corresponding photographs referred to in this report.

Risks Associated with Development

In undertaking hazard assessment studies the concept of 'risk' is subjective. If there is no infrastructure or human presence along a section of shoreline, is there such a thing as a hazard or risk? If the answer is no, then what happens when someone decides to build along that section of shoreline? Any prior hazard assessment in that area is now invalid.

On the other hand, if risks or hazards are identified regardless of specific use, then areas with equal risk will include sites where there is development along with sites where there is no development. In addition, there are areas with identified risks, but they have been adequately mitigated (e.g. through the use of high quality armouring).

Figure 13. Location at Site 4 on Figure 12. Note (a) the near flat-lying beds at the outcrop – armour stone interface and (b) the level nature of the top of the cliff face on the right side of the picture, continuing left to the depression remaining from the Rail Line Slide.

A detailed study of concepts of risk is outside the scope of this report. One can easily see how planners, insurance companies, developers, and private individuals planning to buy property may have different uses for different types of hazard assessment. It depends entirely how risk or hazard is defined, and the purpose for which it is used.

A separate issue is that of ecosystem integrity. There are many natural processes that present a risk to specific coastal ecosystems. This is only true, however, if an ecosystem is assumed to be static. Normal and sudden events may almost completely alter an ecosystem and replace it permanently (on human time scales) with a new ecosystem. Is this a risk?

Risks Caused by the Presence of Infrastructure

In this hazard assessment the authors consider both short-term (what is there now), and long-term risks (what are the risks associated with development). The purpose of the paper is not to examine ecological risk.

A major risk identified in this paper was the widespread presence of rotational slumping and larger translational slides, identified and described in previous sections. The distribution of slumps must be viewed with some caution, however, as it

Figure 14. Armouring at base of the Rail Line Slide. Photo location is at Site 5 on Figure 12.

Figure 15. Armour stone and wood crib work at the base of the Rail Line Slide. Location is just north of Site 4 shown on Figure 12.

reflects historical mechanical and hydrological conditions along the shoreface. These conditions will change if there is development along the Blue Beach fossil cliffs.

Development near the shoreface may include (but is not necessarily limited to) changes such as tree removal, presence of building runoff, parking lot runoff, disposal system water point loading of underlying soil and fractured bedrock, and increased seepage pressures due to increased levels of groundwater flow.

Surface runoff from buildings can be directed back away from the buildings and parking lot. This would act to mitigate some of the common concerns when discussing development along shorelines. If water is directed away from the bank face it could reduce water seepage pressures and decrease the risk of bank failures, or at least delay failures for an unspecified period of time. Care must be taken to ensure that the water is actually directed away from the bank, not just placed farther back from the bank, but at the same time still flowing toward the shoreface through internal structure in the bedrock. The issue of point waste-water loading with respect to disposal systems should be addressed when considering the hazards of shoreface development.

Another common and major concern is loading of the upper surface. This would include such things as the weight of asphalt, cars and buildings. In essence, any net increase in the load acting on the upper surface will potentially increase the risk of shoreface failure in the case of slumps. Undrained loading conditions should be considered in these analyses (City of Ottawa, 2010).

Risk as it Relates to Setbacks

Infrastructure located near shorelines may face numerous hazards. Shoreface erosion and mass movements, flooding, and wind damage are three common hazards. Setbacks for infrastructure built near shorelines should, at a minimum, consider these three main risk factors. Hazards need to be assessed with respect to short-, intermediate- and long-term effects.

Flooding is not identified as a hazard in this report, as the shoreface has a high elevation above the highest high water line. Wind damage is a concern when infrastructure is placed on highly exposed sections of coastline where unusual conditions may exist that are not anticipated in National Building Codes, or where conditions may exceed those planned for such codes. The authors did not examine wind conditions as part of the hazard assessment at this particular location.

This study identified a high or significant potential for small-scale rotational slumps and slides, the potential for large-scale translational slides, and a small hazard potential due to long- or short-term shoreface erosion.

In the section on slumps and rock slides, a working width with respect to the small-scale rotational slumps and slides was determined to be 15 m.

Thus, an absolute minimum setback of 15 m from the nearest point of non-slumped shoreface is required, as that is the width of a single potential slump. This minimum setback leaves no room for error. In addition, it does not incorporate factors such as loading that may increase the probability of a slump and could also increase the actual width of a resulting slump. Standard practice is to incorporate an additional setback of 50% of a potential slide width. Thus, a minimum setback of 23 m is required for development along this section of shoreline.

The Rail Line Slide (up to 43 m wide and 200 m long parallel to the shoreface) is only approximately 250 m north of the southern part of the Blue Beach fossil cliffs. It is clear that a slump of this scale along the southern part of the fossil cliffs would have a severe impact on infrastructure built near the shoreline, even using a 23 m minimum set back.

The probability that a slump of this scale would occur at another part of the Blue Beach fossil cliffs is very difficult to determine, but the possibility cannot be excluded. The authors can only say that it is possible based on the geological evidence.

Mitigation of Hazards

A variety of mitigation efforts could reduce the risk of mass movement along the cliff face of the fossil cliffs. The most obvious is armouring at the base of the cliff face, similar to what is observed at the base of the Rail Line Slide. This would require regulatory approval and may have unanticipated effects on either end of the armoured sections, such increased cliff face erosion. It is also very costly.

Conclusions

Rotational slumps and slides along the Blue Beach fossil cliffs are a hazard to built infrastructure. Individual, small sections of the cliff face near the development site may be stable for decades. Over time, however, rotational slumps develop in response to erosion at the base and along the mid-face of the cliff. The potential maximum width of a slump cannot be determined, but slumps >10 m in width are observed, and 15 m wide slumps are not an unreasonable assumption. Slumping may occur as a gradual process, with migration of slump blocks down the cliff face onto the beach over a 10 year period. This will result in the formation of steep, sub-vertical faces near the top of the cliff. Subsequent rotational slumps at the top of the cliff face will re-initiate the overall process. A specific time frame is difficult to predict for each cycle of erosion.

The potential exists in the proposed development area for larger (e.g. 43 m wide by 200 m long) combination rock slides and slumps of unconsolidated material. Such an event would severely impact potential infrastructure along this section of shoreline. When or if this will occur cannot be predicted with any degree of certainty by the authors. It is a potential hazard.

Long-term average rates of erosion could not be determined with satisfactory precision or accuracy. The authors expect that the average yearly rate of erosion is in the range of ±0.1 m/yr. Erosion rates of this magnitude are not a significant concern with respect to the proposed fossil museum site.

Recommendations

If future development is considered along the Blue Beach fossil cliff section it is necessary to obtain a further engineering geotechnical assessment at the fossil cliffs. This would take into consideration rock mechanics that the authors are not qualified to assess. The geotechnical assessment of slope stability should be undertaken by an independent consultant with the required expertise in this field. Note that the information in this report encompasses much of the information that would be investigated in such a geotechnical assessment

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